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OPTIMAL APPLICATION OF MORRISON'S ITERATIVE NOISE REMOVAL FOR DECONVOLUTION

NASA GRANT NAG 1-485

SEMI-ANNUAL STATUS REPORT

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Dr. George E. Ioup, Principal Investigator
Dr. Juliette W. Ioup, Principal Investigator
Department of Physics
University of New Orleans
New Orleans, LA 70148

OPTIMAL APPLICATION OF MORRISON'S ITERATIVE NOISE REMOVAL FOR DECONVOLUTION

During the fall semester one of the Principal Investigators (GEI) was granted a sabbatical leave by the University of New Orleans. At the end of November he travelled to NASA Langley Research Center to meet with Dr. George M. Wood, Jr., the Technical Monitor for this grant. At that time an oral report was delivered on the progress of the research. A complete report on research completed during the sabbatical is being submitted to the Technical Monitor.

Mr. James Leclere continued his employment begun in the previous grant reporting period. Mr. Leclere worked as a full-time Research Associate from 14 May 1986 to 14 July 1986, and as a part-time Research Associate (20% of time) from 14 July 1986 through the end of the reporting period. His appointment will conclude 31 Dec 1986. Funds will remain after Dec 31 and it is anticipated that they will be used to hire a Graduate Assistant to continue research on the grant.

Mr. Aed M. El Saba completed his research on the effect of varying the input on the optimization of Morrison's iterative noise removal. His thesis, "Effect of Input on Optimization of Morrison's Iterative Noise Removal for Deconvolution" (232 pages), will be submitted for a December graduation. A copy is being sent to the Technical Monitor, and it will be a part of the final report for the grant. A copy of the abstract is attached to this report.

Mr. Abolfazl M. Amini completed work on his thesis, "Optimization of Convergent Iterative Noise Removal and Deconvolution and an Evaluation of Phase-Shift Migration" (441 pages). It will be submitted for a December graduation. A copy is being sent to the Technical Monitor, and it will be a part of the final report for the grant. A copy of the abstract is attached to this report. In his thesis Mr. Amini reports the first simultaneous optimization of noise removal and deconvolution iterations. He worked with the always-convergent iterations of Ioup (1981). His results show clearly when the noise-removal iterations are of benefit and when they are not, in their use in conjunction with the deconvolution iterations. Mr. Leclere applied the same techniques to optimize simultaneously the Morrison noise removal and van Cittert deconvolution iterations which are convergent for the Gaussian response functions employed in the grant research. A paper reporting Mr. Amini's results for seismic data has been accepted by the American Geophysical Union for presentation at their meeting in December. A copy of the abstract is attached. The results for the Gaussian data will be reported in the future.

In the past all optimizations have been done with a wide and a narrow Gaussian for the impulse response function except for those which considered an asymmetric Gaussian (narrow on one side and wide on the other). Mr.

Leclere has investigated Gaussian widths between the narrow and wide Gaussian to determine in more detail how the optimization results vary as a function of Gaussian width. The results can be plotted to good advantage in a three-dimensional perspective type plot. An attempt is being made to present the data in this format. A long-standing question related to instrument resolution concerns the trade-off between resolution and noise. It has been stated that with the availability of deconvolution, the best results may be obtained with less than the highest resolution available in the experiment (Ioup et al., 1983/84). A knowledge of how the signal-to-noise ratio varies with resolution coupled with the optimization results for mean squared error as a function of impulse response width and signal-to-noise ratio could be used to quantify this claim and choose the optimum resolution for the instrument. This is felt to be a fruitful topic for continued research.

Mr. Leclere has also completed the investigation of the claim that Morrison's noise removal combined with a single inverse filtering or deconvolution operation is equivalent to van Cittert's iterative deconvolution. For the most part, the claim has been shown to be true. It is felt that reasonable explanations apply for the exceptions. It is intended to report the results of this research in the literature.

In research related to the grant subject area, Mr.

William S. Kamminga completed work on a thesis, "Gibbs Oscillations for Three Point Sources" (128 pages). It will be submitted for a December graduation. A copy is being sent to the Technical Monitor, and it will be a part of the final report for the grant. A copy of the abstract is attached to this report. Mr. Kamminga's research showed that when there are three point sources, the sidelobes can have a large destructive interference effect for certain separations and relative amplitudes of the sources. This can be an important consideration in many deconvolution problems.

One of the subject areas of study discussed in the grant proposal was the application of iterative deconvolution as a single window in the transform domain. Although such an application must be modified for the inclusion of function-domain constraints, it offers a major advantage in terms of speed. The thesis of Mr. Mark Whitehorn (1981) contains the first one-shot filter study. The important unanswered question is the effect of wraparound on this approach. A Master's student, Mr. Ter Haar BenSuied, has performed a preliminary investigation. The results are thus far very encouraging since wraparound appears to have almost no effect. This means that for many applications the iterative techniques can overcome the problem of lack of speed and compete with much faster methods of deconvolution. It is intended to continue these studies for noisy data and the simultaneous application of noise removal and deconvolution. Eventually constraints will also be included.

Although the application of the optimization studies to data which go positive and negative is not the subject of the grant, investigation of iterative deconvolution and noise removal for such data can nevertheless be revealing when contrasted to the results for nonnegative data and response functions. Mr. Edward J. Murphy has worked with oscillatory type data and has completed a thesis, "Always-Convergent Iterative Deconvolution for Acoustic Non-Destructive Evaluation" (133 pages). It will be submitted for a December graduation. A copy is being sent to the Technical Monitor. A copy of the abstract is attached to this report.

References

G. E. Ioup, 1981, Always-convergent iterative noise removal and deconvolution, Bull. Am. Phys. Soc. 26, 1213.

J. W. Ioup, G. E. Ioup, G. H. Rayborn, G. M. Wood, and B. T. Upchurch, 1983/84, Iterative and function-continuation Fourier deconvolution methods for enhancing mass spectrometer resolution, Intern. Jour. Mass Spec. and Ion Processes 55, 93-109.

M. A. Whitehorn, 1981, Always-convergent iterative noise removal and deconvolution for image data, M. S. thesis, University of New Orleans.

Effect Of Input On Optimization Of Morrison's Iterative Noise Removal For Deconvolution

A Thesis

Presented to

the Faculty of the Graduate School

University of New Orleans

In Partial Fulfillment

of the Requirements for the Degree of

Master of Science in Applied Physics

by

Aed M El-saba

December 1986

Abstract

Morrison's iterative method of noise removal can be applied for both noise removal alone and noise removal prior to deconvolution. This method is applied to noise of various noise levels added to data to determine the optimum use of the method.

The inverse filter is calculated by taking the inverse discrete Fourier transform of the reciprocal of the transform of the response of the system. The method of deconvolution used consists of convolving the data with the inverse filter. Deconvolution of non-noisy data is performed and the error is calculated by comparing the deconvolved results to the original input f.

A triangular and rectangular type input is selected and convolved with narrow and wide response Gaussian functions to produce the data sets to be analyzed. The types of noise added to the data are constant and ordinate-dependent Gaussian distributed noise. The noise levels of the data are characterized by their signal-to-noise ratios. L1 and L2 norms for errors are employed in the optimization.

Tables of results and figures are both included to show the results of optimization for both Gaussians, for both noise types, and for both norms.

The input is selected to contrast with the input of Leclere which consists of narrow Gaussians. The results of the two optimizations are compared. The current input is also scaled by multiplication by a constant to illustrate

the effect of scaling.

OPTIMIZATION OF CONVERGENT ITERATIVE NOISE REMOVAL AND DECONVOLUTION AND AN EVALUATION OF PHASE-SHIFT MIGRATION

A Thesis

Presented to

the Faculty of the Graduate School

University of New Orleans

In Partial Fulfillment

of the Requirements for the degree of

Master of Science in Applied Physics

by

Abolfazl Mahyari Amini

December 1986

ABSTRACT

Noise removal and deconvolution are often considered to be a necessity for data processing work. There are many methods of deconvolution and noise removal available Among those are the iterative methods.

The iterative method used for this research is primarily the always-convergent method of Ioup (AC), which includes noise removal and deconvolution iterations. It has been optimized for Gaussian response functions and a seismic wavelet. In addition to the AC method, the reblurring procedure of Kawata and Ichioka (RB), and least squares inverse filtering (LS) have also been used for seismic data. No noise removal method is used prior to unfolding when working with the RB and LS methods. The deconvolution performance by the AC and RB methods (at the optimum iteration number) is compared to the LS performance for SNR's (signal-to-noise ratios) of 10 , 40, and 150. The AC method is also optimized for the wide Guassian, SNR's of 24, 43,55,...,155 and 11,23,36,...,754 for the narrow Gaussian.

Deconvolution is one data analysis technique used in reflection seismology; another is migration. In this thesis the phase-shift method of migration and modeling is evaluated and the results are compared to Stolt's approach.

A single spike is fed into the phase-shift modeling and migration methods; a hyperbola and a half circle are obtained, respectively.

This thesis introduces a method by which one can find the optimum iteration number for deconvolution of sampled data. The method employs the mean squared error (MSE), the square of the difference between the deconvolved result and the input, for optimization. The MSE decreases as the deconvolution iterations proceed, but at the optimum iteration number, it starts to increase. The research is carried out for three types of data: (1) seismic, (2) narrow Gaussian (fast convergence), (3) wide Gaussian (slow convercent).

This procedure can be repeated for various signal-to-noise ratio (SNR) data sets to obtain plots of deconvolution and noise removal iteration number vs SNR. By knowing the SNR one can find the optimum iteration number from the plots, and therefore the application of an equivalent window becomes feasible.

Optimization of Convergent Iterative Deconvolution for Seismic Data

ABOLFAZL M. AMINI, GEORGE E. IOUP, JULIETTE W. IOUP, AND REGINALD POWE (all at Department of Physics and Geophysical Research Laboratory, University of New Orleans, New Orleans, LA 70148)

Statistical computer simulation is used to describe the optimum use of two convergent iterative deconvolution techniques for seismic data. The always-convergent iterative method (AC) of Ioup and the reblurring/mirror image iterative procedure (RB) of Kawata and Ichioka and LaCoste are applied to synthetic data consisting of the convolution of a minimum phase wavelet with a varying-separation, same-polarity spike train. By studying the mean squared error versus iteration number for fifty noisy data sets, one can calculate the mean optimum iteration number and its standard deviation, as well as the average mean squared error and its standard deviation. It is assumed that the optimization can be characterized by its dependence on the signal-to-noise ratio (SNR). Trials are run for SNR's of 150, 40, and 10, and for noise-free data. Additional SNR's are included for the AC method. The results are given and compared to those for least squares inverse filtering. Cases at each noise level are used to show sample results of the deconvolution at the optimum iteration number. For the AC method, noise removal iterations precede the deconvolution iterations, and these must be optimized simultaneously. Consideration is given to the fact that there is nothing about the iterative methods which dictates the choice of the L2 norm for minimization. Extensions of the results by including more test cases or by application to other data are discussed.

1. 1986 Fall Meeting

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3. G. E. Ioup
   Physics Department
   University of New Orleans
   New Orleans, LA 70148

   (b) (504) 286-6709

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GIBBS OSCILLATIONS FOR

THREE POINT SOURCES

A Thesis

Presented to

The Faculty of the Graduate School

of the University of New Orleans

In Partial Fulfillment

of the Requirements for the Degree of

Master of Science in Applied Physics

by

William S. Kamminga

December 1986

ABSTRACT

Any physical measurement system is band-limited and will act as a low-pass filter. The lack of higher frequency components in the output can produce Gibbs oscillations when the input is obtained by unmodified deconvolution. This work analyzes the causes and effects of errors which the Gibbs oscillations will induce in the deconvolved result for an input of three point sources. Initially linear shift-invariant systems are analyzed to develop the mathematics associated with the causes of Gibbs oscillations. This includes a discussion of the principal solution which is obtained when the output is deconvolved with the band-limited system impulse response. Gibbs oscillations are discussed from a historical perspective and formulations are developed using both the Fourier series and the Fourier integral. The mathematics is then developed for an input of three point sources. In order to analyze the effects of varying amplitudes and peak separations, two-dimensional plots are produced. Analysis procedures are discussed for determining the effects which the Gibbs oscillations have on the apparent heights, locations, and areas of the deconvolved peaks. A case is analyzed where the summation of the negative

sidelobes of adjoining peaks completely obliterate the existence of a middle peak. The results are reported in dimensionless parameters which can be applied to any system. An example for a specific system is discussed.

ALWAYS-CONVERGENT ITERATIVE DECONVOLUTION FOR ACOUSTIC NON-DESTRUCTIVE EVALUATION

A Thesis

Presented to

the Faculty of the Graduate School

of the University of New Orleans

In Partial Fulfillment

of the Requirements for the Degree of

Master of Science in Geology and Geophysics -

Geophysics Option

by

Edward J. Murphy

December 1986

Abstract

Acoustic energy sources are used in many scientific applications including the analysis of materials. The information within such a signal may be more easily extracted if it is first processed on a computer. One widely used technique of data processing is deconvolution. The particular deconvolution method investigated for this work is the Always-Convergent Method of Ioup (1981). It involves two separate procedures: a noise removal iteration related to Morrison's Smoothing, and a deconvolution iteration related to van Cittert's Deconvolution, which eliminates the effects of the impulse response of the system.

Background material for these procedures is presented and discussed. They are described in both the time and frequency domains. Always-Convergent deconvolution may be more accurate in the time domain since it can be used directly on the original data. However, it is often easier to understand its effects in the frequency domain.

The Always-Convergent technique was applied to data recorded during the quantitative analysis of materials through Non-Destructive Evaluation (NDE) in which ultrasonicsignals were used to detect flaws in substances such as composites. After the signal was processed the normalization was investigated. One must be able to examine a particular component of a time series and determine its significance relative to the source signal. The magnitude

of an event will be markedly different for a reflection from the front surface of a material than for one from a crack or a discontinuity within it. Various methods of normalization were tested and the results tabulated. The most effective method used the change in the sum of the absolute values of the amplitudes in the signal before and after processing.